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Benthic macroinvertebrates as indicators of ecological fragility of small Rivers ('Igarapés') in a bauxite mining region of Brazilian Amazonia*

by

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Abstract

Benthic macroinvertebrate communities were studied in the igarapés Saracá, Caranã and Água Fria near Porto Trombetas, Municipality of Oriximiná, State of Pará, Brazil (1°25' to 1°35'S and 56°15'to 56°W). The main objective was to investigate the potential use of the benthic macroinvertebrates community as indicators of the ecological fragility of the igarapés located in an area of the Amazon basin influenced by bauxite mining. These aquatic ecosystems have low pH (< 4.5); low electrical conductivity (< 90 $\mu S\ cm^{-1}$); low or undetectable total alkalinity; low nutrient concentrations in the sediment, which implies low primary productivity; low species richness; low secondary productivity; and low rates of organic matter decomposition. The benthic macroinvertebrates utilize mainly allochthonous organic matter. Some areas of the ecosystems investigated have been modified by bauxite tailings (especially in their sediment granulometry), by a dam formed by railroad construction (which altered the hydrodynamics and eliminated the terra firma vegetation), and by accidental discharges of various minerals from the railroad traffic and bauxite mining. These factors have drastically modified the local benthic macroinvertebrate communities. The value of benthic macroinvertebrates as indicators of ecological fragility, the health of the ecosystem investigated, and water quality is evaluated.

Keywords: **Benthic macroinvertebrates, Amazonia, bauxite, ecosystem health, water quality.**

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Introduction

In lotic ecosystems, hydrological conditions play a fundamental role in determining the distribution and density of benthic macroinvertebrates and pollutants, as well as in their interactions (JANSSENS DE BISTHOVEN et al. 1992). Many igarapés (small rivers) in Amazonia, for example Saracá, Caranã, and Água Fria Igarapés near Porto Trombetas, Municipality of Oriximiná in the Brazilian State of Pará undergo large fluctuations in water level because of the heavy regional rains. In these systems, the distributional patterns of the benthic macroinvertebrates are different during the rainy and dry seasons.

In the Porto Trombetas region, innumerable bodies of water have been directly or indirectly affected by bauxite mining activities. Chiefly, several igarapés have been dammed for construction of a railroad, with consequent profound changes in their hydrodynamics and the organic matter content and granulometry of their sediments. In addition, bauxite ore is present in some stretches of the riverbeds; bauxite tailings have been dumped into Caranã Igarapé; and more recently, a tailings containment basin overflowed into Água Fria Igarapé.

Because of their characteristic acid pH, low electrical conductivity, low total alkalinity, and low nutrient concentrations in their sediment (CALLISTO et al. 1998), these igarapés have been shown to be quite fragile ecologically. Small changes in their structure and function can result in unpredictable ecological changes, including complete elimination of benthic organisms, a certain indication of ecosystem death (CALLISTO 1996).

The acid pH (< 4.5) characterizes these ecosystems as having low primary productivity, low species richness, low secondary productivity, and low rates of decomposition of organic matter (CALLISTO 1996). The benthic macroinvertebrates living in these igarapés are adapted to these conditions, using allochthonous organic matter for maintenance (CALLISTO & ESTEVES, 1998a).

Based on the taxonomic composition, structure, and seasonal dynamics of the macrobenthos, the present study proposes the benthis macroinvertebrate communities as indicators of ecological fragility in some aquatic ecosystems, specifically in a bauxite mining region in Central Amazonia.

Ecological impacts and modifications

In the dammed stretches of the igarapés, the benthic macroinvertebrate communities find themselves in a new ecological succession process. Because of flooding of extensive areas of terra firma vegetation, followed by input of allochthonous organic matter into the ecosystem, the environmental conditions were totally altered. Concurrently, the temporal superposition of species was modified, as shown by BARBIERI (1995).

In the Porto Trombetas region, three types of ecological conditions were identified:

1. In the natural areas of the igarapés (Stations Saracá-1, Caranã-1, and Água Fria-1), the natural environmental conditions are preserved, free of direct or indirect influence from mining activities. In these areas, the macroinvertebrates live in perfect equilibrium with the natural characteristics of the ecosystems, with aggregated distributions in the available microhabitats, colonizing a nutrient-poor, sandy sediment. These

stations are considered as controls ('white') in relation to the structure and distributional patterns of the benthic macroinvertebrates (Figures 1, 2, and 3).

2. In the areas dammed by railroad construction, drastic changes were identified in the hydrodynamics of Saracá and Caranã Igarapés. With damming came flooding of extensive areas of terra firma vegetation, killing the trees, which were not adapted to permanent inundation. This may be attributed to drowning of the vegetation and the increase of toxic substances such as malate and ethanol in its roots (MITSCH & GOSSELINK 1993). At present, those stretches of the igarapés present a scene of destruction, with rotting, leafless tree trunks, locally termed 'paliteiros' (toothpick trees). The characteristics of those areas changed from lotic to lentic, favoring colonization by rooted aquatic macrophytes with floating leaves (*Nymphoides* sp., Marantaceae) and non-rooted floating plants (*Salvinia* sp., Salviniaceae), mainly in the littoral zone. There were also marked changes in water color from clear and transparent to strongly tea-colored, caused by the presence of humic substances derived from decomposition of organic matter. The organic matter content of the sediments increased (inferred from the concentrations of organic C, total N, and available P) (FONSECA et al. 1998a). Howeverer, we did not observe similar changes in the structure and distribution patterns of the benthic communities, in spite of similar impacts from mining activities. Thus, at Station Saracá-2, we observed higher taxon richness and organism densities, especially of larvae of Chironomidae (CALLISTO 1997). At Station Caranã-2, in addition to higher sediment organic matter content, there was a greater change in granulometric composition, as a result of spills of bauxite particles from the railroad cars. In this stretch, there was lower taxonomic richness and lower densities of benthic organisms. The predominance of oligochaetes in this area suggested that sediment organic matter content was higher there. It is also possible that in this stretch the benthic macroinvertebrates were influenced by production of sulfide gas and methane from decomposing organic matter in the sediment (CALLISTO & ESTEVES 1998b).

3. In the parts of the igarapés with bauxite, we identified the most profound and drastic changes in water quality. At Stations Caranã-3 and Água Fria-2, the presence of bauxite tailings substantially altered the distribution of the benthic macroinvertebrates. Thus, in the stretch of Caranã Igarapé where bauxite tailings were dumped for ten years, during the rainy seasons of 1994 and 1995 the benthic macroinvertebrate fauna totally disappeared. Data from the present study suggest that recovery of this stretch of Caranã Igarapé will be slower than in the bauxite-impected area of Batata Lake, which has been gradually colonized by benthic macroinvertebrates (FONSECA et al. 1998b). This is probably because of the hydrodynamic differences between the two bodies of water. Batata Lake is a receiver ecosystem, where organic matter accumulates gradually in the sediment. Caranã Igarapé is a lotic system, and its vegetationless banks are eroding rapidly and depositing inorganic sands and larger bauxite particles in the channel (FONSECA et al., in press a), where finer particles are transported and heavier ones deposited. Soon, with lower organic matter concentrations in the sediment and drastic changes in its granulometric composition, the benthic macroinvertebrates may have difficulty in recolonizing this stretch.

In Água Fria Igarapé we observed a gradual increase of the influence of bauxite tailings, because of overflow from a nearby containment basin. Water level varies most in this system, which is directly influenced by the hydrological cycle of the Trombetas River to which it is permanently connected. Data from the present investigation showed

that the distribution of the benthic macrofauna, dominated by larvae of Chaoboridae and some genera of Chironominae, underwent drastic quantitative changes because of the enlargement of the 'tailings patch' in the igarapé. By the November 1995 sampling period, the tailings had been carried to the juncture with the Trombetas River, resulting in elimination of the macrofauna at Station Água Fria-3.

Ecological fragility

During two years of investigations in Saracá, Caranã, and Água Fria Igarapés it was possible to characterize the structure and distribution of the benthic macroinvertebrate communities and their relationships with certain abiotic variables of the water and sediment. These systems displayed particular ecological characteristics that can be interpreted and placed in the context of 'ecosystem fragility'.

Application of the concept of ecosystem fragility to Amazonian igarapés in the area subject to bauxite mining activities is fundamentally linked to two main situations. The first considers a natural ecosystem which after a disturbance does not return to the previous state. A second situation occurs when after an environmental disturbance caused by direct or indirect human influence, the system returns after a certain time to the previous state. In the case of the Porto Trombetas igarapés, we observed that because of the intensely modified environment, return to the previous state is extremely difficult.

The changes in Caranã Igarapé caused by dumping of bauxite tailings serve as an example of ecological fragility. Although dumping was discontinued in 1989, the benthic macroinvertebrates have not succeeded in recolonizing the sediment in that stretch of the igarapé. These observations are based on comparisons with the natural station (Caranã-1) as a reference for pre-impact conditions. Data from the present investigation permit us to hypothesize that the ecological changes caused by dumping of bauxite tailings into Caranã Igarapé were responsible for the development of a new process of ecological succession. A new taxonomic structure of the macrobenthic organisms is becoming established.

Benthic macroinvertebrates as bioindicators of ecological fragility

The characteristics peculiar to the bodies of water studied (acid pH and low electrical conducivity, total alkalinity, and sediment organic matter content) make the food webs of the benthic macroinvertebrates of these systems dependent on allochthonous sources of organic matter (CALLISTO & ESTEVES 1998a). With the changes caused by bauxite mining activities, the distribution of the benthic macroinvertebrate communities was also changed. In this context, data from this study suggest that the influence of bauxite tailings was responsible for the drastic loss of benthic fauna in Caranã Igarapé. In Água Fria Igarapé the beginning of this process can be observed, with a gradual loss of macrobenthic biodiversity in the areas being impacted by tailings. On the other hand, in the dammed areas, there was an increase in taxon richness and biomass of the benthic macroinvertebrates. Thus it was observed that the stretches of the igarapés impacted by bauxite tailings are ecologically more fragile.

Resumo

Foram estudadas as comunidades de macroinvertebrados bentônicos nos igarapés Saracá, Caranã e Água Fria próximo à localidade de Porto Trombetas, Municipio de Oriximiná, Estado do Pará, Brasil (1°25' a 1°35'S e 56°15' a 56°W). O objetivo principal foi investigar a potencial utilização das comunidades de macroinvertebrados bentônicos como indicadoras da fragilidade ecológica dos igarapés localizados em uma área na Amazônia Central sob influência das atividades de uma mineração de bauxita. Estes ecossistemas aquáticos possuem águas ácidas (pH < 4,5); baixa condutividade elétrica (< 90 µS cm^{-1}); reduzida ou não detectável alcalinidade total; baixas concentrações de nutrientes no sedimento, que determina baixa produtividade primária; baixa riqueza de espécies; baixa produtividade secundária; e reduzidas taxas de decomposição de matéria orgânica no sedimento. Os macroinvertebrados bentônicos utilizam principalmente matéria orgânica de origem alóctone. Alguns trechos dos ecossistemas investigados foram modificados por lançamento de rejeito de bauxita (especialmente a composição granulométrica dos sedimentos), por represamento devido à construção de uma rodoferrovia (que alterou a hidrodinâmica e eliminou a vegetação de terra firme), e por queda acidental de materiais inorgânicos durante o tráfico na rodoferrovia. Estes fatores modificaram drasticamente as comunidades de macroinvertebrados bentônicos. Os resultados obtidos permitiram evidenciar o papel dos macroinvertebrados bentônicos como indicadores de fragilidade ecológica, qualidade de água e saúde dos ecossistemas estudados.

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References

BARBIERI, R. (1995): Colonização vegetal em habitats formados pela sedimentação do rejeito de bauxita em um lago amazônico (lago Batata, PA). - PhD-thesis, PPG-ERN, Universidade Federal de São Carlos, São Carlos, SP, 215 p.

CALLISTO, M. (1996): Macroinvertebrados bentônicos em quatro ecossistemas lóticos amazônicos sob influência das atividades de uma mineração de bauxita (Porto Trombetas, Pará). - PhD-thesis, Rio de Janeiro, UFRJ, PPGB/IBFCCF, 140 p.

CALLISTO, M. (1997): Larvas bentônicas de Chironomidae em quatro ecossistemas lóticos amazônicos sob influência das atividades de uma mineração de bauxita. - Universidade Federal de São Carlos, S.P. Anais VIII Sem. Reg. Ecol. **8**: 89-98.

CALLISTO, M. & F.A. ESTEVES (1998a): Categorização funcional dos macroinvertebrados bentônicos em quatro ecossistemas lóticos sob influência das atividades de uma mineração de bauxita na Amazônia Central (Brasil). - Oecologia Brasiliensis, vol. Ecologia de Insetos Aquáticos: in press.

CALLISTO, M. & F.A. ESTEVES (1998b): Biomonitoramento da macrofauna bentônica de Chironomidae em dois igarapés amazônicos sob influência das atividades de uma mineração de bauxita. - Oecologia Brasiliensis, vol. Ecologia de Insetos Aquáticos: in press.

CALLISTO, M., GONÇALVES, J.F., Jr. & J.J.L. FONSECA (1998): Benthic macroinvertebrates of four Amazonian streams influenced by bauxite mining (Brazil). - Verh. Internat. Verein. Limnol. **26**: 983-985.

FONSECA, J.J.L., GONÇALVES, J.F., Jr. & M. CALLISTO (1998a): C, N, P e composição granulométrica do sedimento em quatro ecossistemas lóticos amazônicos sob influência de uma mineração de bauxita. - Universidade Federal de São Carlos, SP. Anais VIII Sem. Reg. Ecol. **8**(2): in press.

FONSECA, J.J.L., CALLISTO, M. & J.F. GONÇALVES, Jr. (1998b): Benthic macroinvertebrate community structure in an Amazonian lake impacted by bauxite tailings (Pará, Brazil). - Verh. Internat. Verein. Limnol. **26**: 2053-2055.

JANSSENS DE BISTHOVEN, L., VAN LOOY, E., CEUSTERS, R., GULLENTOPS, F. & F. OLLEVIER (1992): Densities of *Prodiamesa olivacea* (MEIGEN) (Diptera: Chironomidae) in a second order stream, the Laan (Belgium): relation to river dynamics. - Neth. J. Aqua. Ecol. **26**(2-4): 485-490.

MITSCH, W.J. & J.G. GOSSELINK (1993): Wetlands. - 2nd. ed. Springer-Verlag, New York, 335 pp.

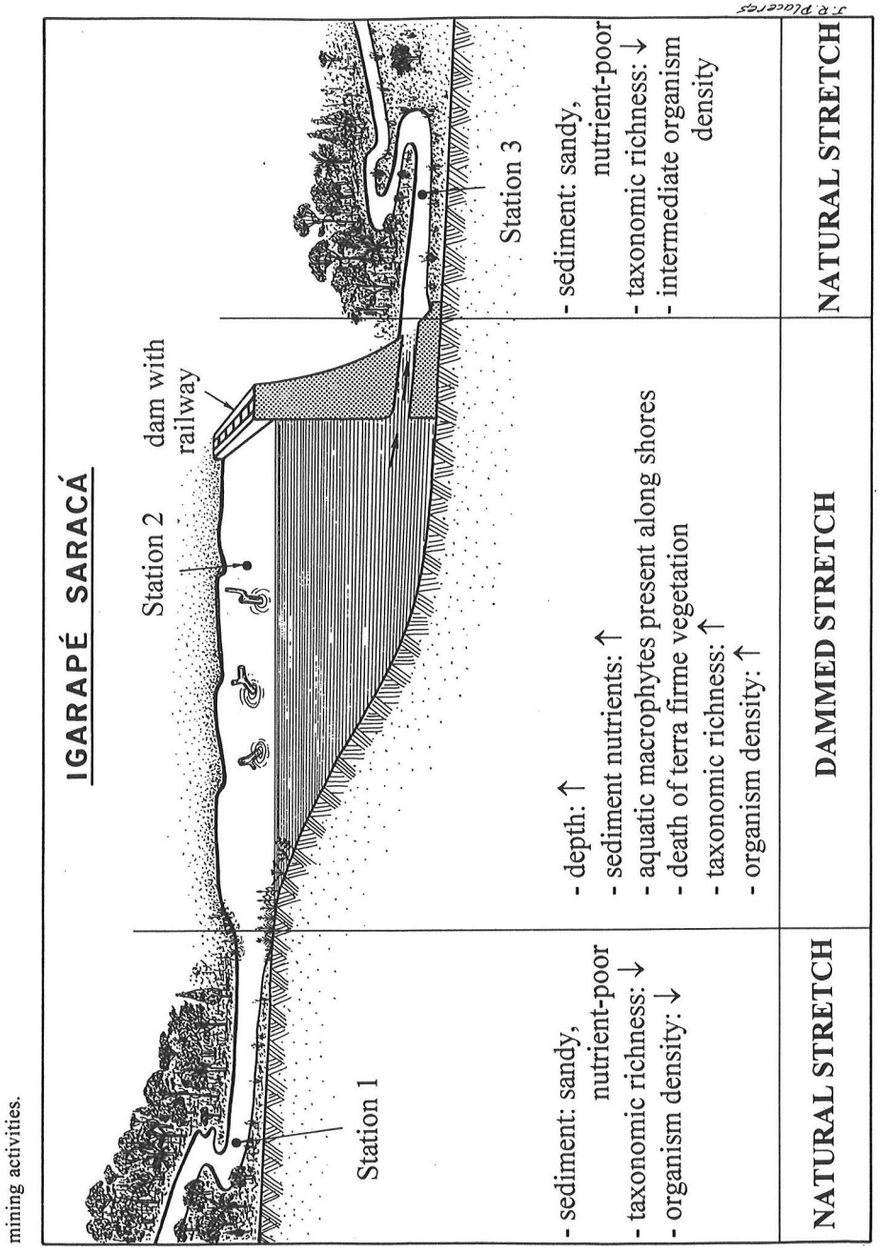

Fig. 1:
Diagram of the main ecological characteristics of the natural and dammed stretches of Saracá Igarapé, showing the changes caused by bauxite mining activities.

Fig. 2:
Diagram of the main ecological characteristics of the natural, dammed, and bauxite-impacted stretches of Caranã Igarapé and Batata Lake.

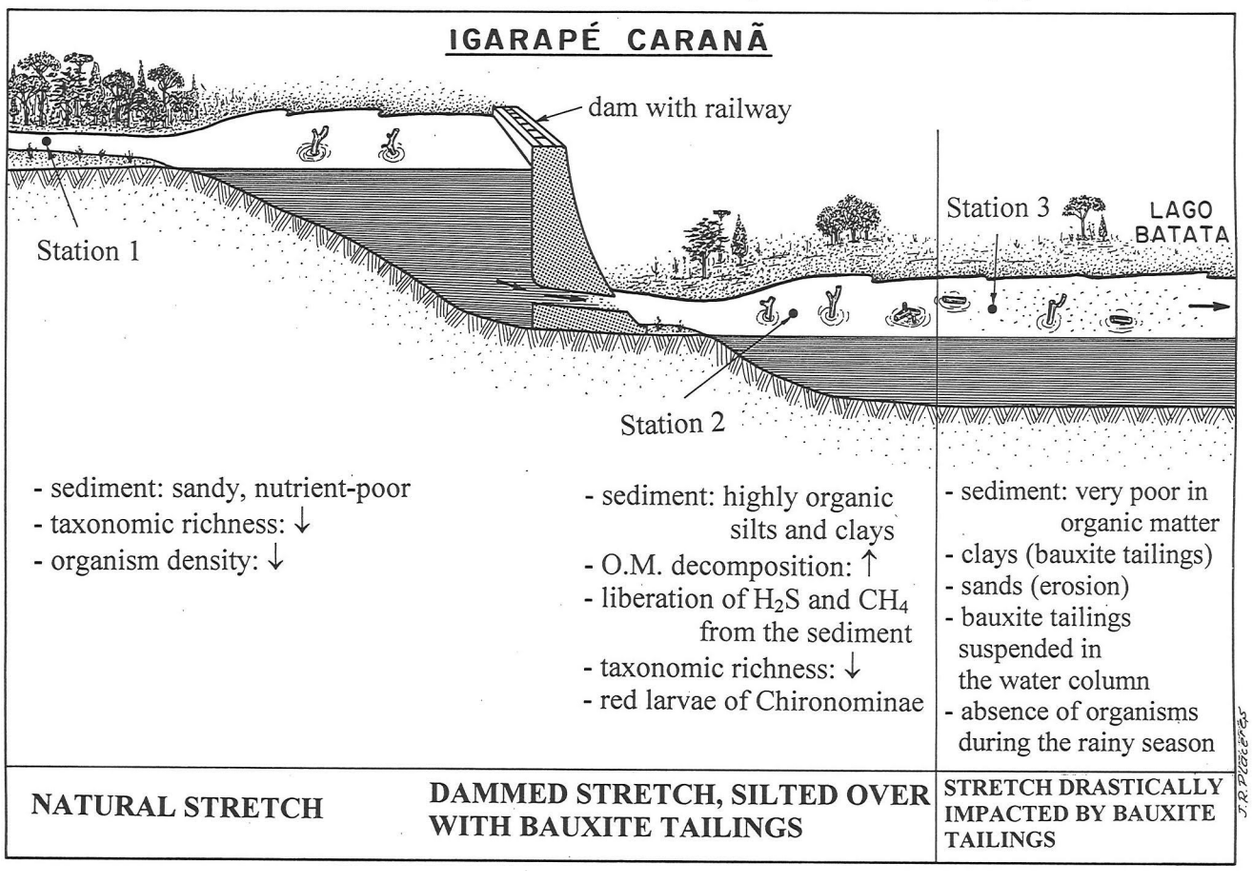

Fig. 3:
Diagram of the main ecological characteristics of Água Fria Igarapé in 1994 and 1995.